Taking into Account Sensory Knowledge: The Case of Geo-technologies for Children with Visual Impairments

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ABSTRACT
This paper argues for designing geo-technologies supporting non-visual sensory knowledge. Sensory knowledge refers to the implicit and explicit knowledge guiding our uses of our senses to understand the world. To support our argument, we build on an 18 months field-study on geography classes for primary school children with visual impairments. Our findings show (1) a paradox in the use of non-visual sensory knowledge: described as fundamental to the geography curriculum, it is mostly kept out of school; (2) that accessible geo-technologies in the literature mainly focus on substituting vision with another modality, rather than enabling teachers to build on children's experiences; (3) the importance of the hearing sense in learning about space. We then introduce a probe, a wrist-worn device enabling children to record audio cues during field-trips. By giving importance to children's hearing skills, it modified existing practices and actors' opinions on non-visual sensory knowledge. We conclude by reflecting on design implications, and the role of technologies in valuing diverse ways of understanding the world.

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H.5.m. Information Interfaces and Presentation (e.g. HCI): :Miscellaneous; K.4.2 Social Issues: Handicapped persons/special needs

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Sensory knowledge, Maps, Design, Visual Impairments, Education, Wearable, Geography, Probe

INTRODUCTION
There is a long tradition in academia to favor vision and textuality, perceived as the best or only way to produce and share knowledge [41]. However, an increasing number of scholars now focus on the other senses [10]: this is referred to as the *sensory turn*. More specifically, they focus on how socio-cultural factors shape our perception, and how our senses influence what and how we know about the world [36]. This interest originates from concerns that the priority given to vision diminishes other *sensory knowledges*, i.e. implicit and explicit knowledge guiding our uses of our senses [64]. For instance, we learn early to distinguish and name colors but not tastes or smells [68].

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In HCI this sensory turn can be identified, for instance, in the use of sensory ethnography [73], or the interest for embodied experiences [23, 43, 1]. However, designers rarely question explicitly which, and whose, sensory knowledge they support, and how it defines the experience they propose.

In this paper, we investigate how this scholarship could open new design perspectives for learning technologies. More precisely, we focus on how children with visual impairments use their senses in geography classes and how educational technologies could foster sensory knowledge. This case is of particular interest, because geography teachers generally relies on *visual* tools and representations (e.g. drawing of subjective maps, cameras)–thus not always appropriate for this public. Moreover, the geography curriculum aims to help children understand the spatial dynamics of the world they live in, to ensure they have the tools necessary to exert their right to civic participation [40]; Yet, if children with visual impairments' views and specific sensory knowledge are not well represented or supported, it may limit their ability to participate [81]. Which could reinforce the participation restrictions people with disabilities experience [86].

While many accessible geo-technologies can be used to teach geography, we argue that they are not sufficient: Indeed, they mainly focus on substituting vision with another modality (e.g., tactile or audio maps [92, 7]), rather than enabling teachers to build on children's experiences of space, or support the acquisition of non-visual sensory knowledge.

Our investigation relies on a three-step research process:

1. During an 18 months field-study on teaching practices, we focused on the use of non-visual sensory knowledge during field-trips for the teaching of geography in primary education. It involved 50 visually impaired children in an organization providing them with all needed services (e.g., rehabilitation, assistance at school etc.), in the spirit of action research [89] and participatory design [78]. Our first contribution is the description of these *field-trips* practices. We show (1) that acquiring techniques of hearing [1] is im-

[1] We use the verb hear rather than listen on purpose, as a translation of the French verb *entendre* used by the research participants.

portant for children to learn about space and geography; Yet (2) there is a lack of legitimacy for these practices. For instance, teachers are not taught about how best to describe sensory cues, and field-trips were framed (both by teachers and children) as *pleasant*, but not necessarily as *efficient* for the formal learning valued at school; (3) There are no tools used, or proposed by the literature, to support this kind of field-trips. These findings hint at a paradox: teachers state children need to develop hearing techniques to learn geography, but there is a general lack of support for these practices as they have little legitimacy.

2. We therefore investigated whether introducing a device supporting the use of hearing techniques and audio material in this context could improve their legitimacy. Our rationale was that if we made their uses more visible, it would open opportunities to discuss and renegotiate what is considered as valuable learning. We thus conducted eight interviews with carers to refine the possibilities of a design intervention. This led us to co-design a probe with a group of five children, a wrist worn device enabling to record and play audio data.

3. We then deployed this probe during two geography field-trips with five children and two caregivers. We observed and discussed its use with all participants. We show that (1) adults used the probe as a reflexive tool on their practices; (2) the probe provided children with more occasions to be active in the construction of meaning, both during and after the field-trip, which they described as "*making it easier to be understood [by adults]*." Moreover, interviews suggest that (3) it changes children's and teachers' perspectives on the utility of hearing techniques and use of auditory material at school, indeed making them more legitimate.

To conclude, we discuss how our focus on supporting non-visual sensory knowledge (1) opens new perspectives for the use of auditory representations in geography for *all*, (2) showing the potential to put an emphasis on the sense of hearing when designing embodied interaction [1], instead of as a simple support to the visual; and (3) underlines the advantages of using probes to identifying and negotiating values in the design process.

THE SENSORY TURN IN GEOGRAPHY SCHOLARSHIP

In geography, scholars interested in the sensory turn have long challenged vision as the primary or only way of knowing about space and landscapes [19, 82, 2]. This is particularly the case in human geography, which refers to the branch of Geography concerned with the spatial organization of human activity [15].

Senses and Embodiment in Human Geography

Scholars have argued that space is known through embodied practices (e.g., walking [55], cycling [81, 80], or using a wheelchair [67]), and that different embodiments and practices create different knowledge about space [55, 65]. For instance, children are more attentive to certain sensory aspects of space than others, these variations being tied to where they live and the cultural practices of their community [4]. Children's everyday environment can thus provide rich examples of social and spatial phenomena (e.g., differences between rural and urban areas) [4, 12], as well as opportunities to exert their citizenship [81, 56, 63]. These local environments exemplify the interaction of factors of various scales (e.g., local, regional, national, international) and types (e.g. topography, history, policy). Field-trips provide additional, tailored examples. They consist in getting to a nearby place (e.g., museum, farm) from which pupils can get firsthand knowledge [51, 22, 87, 42, 5]. However, the visual sense remains central in this approach–so how can children learn geography non-visually?

Space through the Sense of Hearing

The sense of hearing is central in our case-study. Let's note that the senses are never separated and experienced alone [75], but that we can set apart a given stimuli, experienced through a given sense, to give it meaning [4]. Thibaud [82] highlights that "*when you hear a place, you hear a specific social organization of sound as well as the way in which people interact and relate to each other.* " (p. 10). Augoyard and Torgue [3] describe the environment as an *instrumentarium*, in which sound "*is always shaped subjectively [...]. There is no universal approach to listening: every individual, every group, every culture listens in its own way*" (p.4). In doing so, they highlight the need to reflect on the acquisition of ways of hearing (i.e., *sensory knowledge* [64]). Furthermore, Thibaud note that "*while vision tends to implement too great a distance between the perceiver and the perceived, and while olfaction tends to produce overly diffuse and volatile phenomena, audition can mix the affective with the cognitive, the universal with the singular in a very balanced way*" ([82], p.12). In other words, when knowledge is primarily visual it risks obscuring lay experiences and knowledge; And sound can be used to learn about human geography if one acquires specific hearing skills. However, there are no clear guidelines about how to teach them to children.

RELATED WORK

To further contextualize our research, we first provide some background on visual impairments, and outline our definition of design as a material-discursive practice. We then review three bodies of work: accessible geo-technologies, technologies for field trips and multisensory technologies.

Visual impairments and disability

Visual Impairments designate a broad range of visual abilities (from mild visual impairment to blindness). They have a low prevalence in European children (severe visual impairments rate vary between 0.15-0.45/1000 children), and a very diverse range of causes and associated impairments [44]. It follows that "children with visual impairments" designates a very diverse group, with diverse sensory schema. Disability however can not be reduced to impairments: it should instead be considered as the complex interactions between bodily and physiological characteristics, and the built, social and cultural environment [86]. For instance, to this day children with disabilities remain discriminated against, even in well-developed inclusive educational systems [35, 31].

Design as a material-discursive practice

As design practices partly define the built environment, designers should be careful of their understanding of disability, which they embed in their propositions [33]. Critical disability scholars warn against taking a deficit model, i.e. to consider technologies **only** as a way to rehabilitate or cure disabled bodies [29, 28]. This is the basis of their criticism of Universal Design [90, 34] which, they argue, erases disability instead of valuing a diversity of embodiments and abilities. In turn, it reinforces discourses about what kinds of bodies are "better": the materiality of design shapes discourses and self-perceptions. In this view, that we espouse, design should rather focus in proposing a multiplicity of ways to access [33] and know [36] the world. A concern shared with some scholars working with geo-technologies (e.g., [49]).

Geo-technologies

By the term geo-technologies, we refer to technologies used to understand and represent space [63]. They include for instance global positioning system (GPS) devices and geographic information systems (GIS), which are common in everyday lives and in learning environments [57]. These technologies implement a visually centered approach to space, providing a *god's eye view* which in many cases increased spatial discriminations [49]. There is thus a need to divert them, or design other technologies, if we want alternative points of views to be recognized [71, 63, 81]. For example, Matos [66] proposed an application for learning a rare whistled language. This language depends on the topography. Children can create an imaginary topography, or recreate an existing one. This visual interface supports a specific sensory knowledge (through whistling and hearing) of physical geography–although this is not how the author frames it. To our knowledge, there is no such proposition to support the geographic knowledge of people with visual impairments.

Related to our specific case (experiential learning of geography by visually impaired children), we identify three core research themes: tools to ease everyday navigation [88], tools for spatial rehabilitation [77, 27], and accessible maps [92]. The first two adopt the position criticized in the above paragraph: they aim at enabling a "normal" functioning, which is necessary, but not our focus. In contrast, maps have the potential to support a diversity of knowledges and points of view [49, 63, 81]. However, the research on this topic mostly focuses on how to best translate visual information in another modality, as well as the usability and cognitive gains they provide [92, 7, 24, 11, 79, 83].

Technologies and field-trips

The research literature on educational technologies for field-trips offers a number of insights, though it focuses mostly on the scientific curriculum. It emphasizes the importance of the scaffolding of the experience to ensure reflexivity [74, 17]. This includes the design of introductory, on-site and follow-up activities. Many research projects thus aim at scaffolding activities using technologies, either through an environmental intervention [76] or by equipping children with mobile devices to gather and/or handle data [47, 54, 48]. For instance, Lo and Quintana have investigated the use of hand-held computers by learners during nomadic inquiry for science courses [54]: they enabled children to record photos, videos and audio to answer specific questions, and to tag them to support reflection and exchange. They analyzed their strategies and found, among other things, that **audio recordings are far less used**, and only to record discussions. Sensory experiences are not addressed in this body of work.

Technologies and sensory experiences

Our project can be linked to technologies mediating embodied experiences for learning. Full-body interaction for instance exploit sensori-motor processes. These interfaces are based on a constructionism approach, i.e. that learning is most efficient when acquired through doing in a rich environment (see also [43]). Such technologies are often deployed inside facilities [60, 59, 91, 69] (although the recently proposed "World-as-Support" paradigm [61] may change that) and mainly rely on visual stimuli and feedback (e.g., use of pico-projectors). Directing visual attention for learning is a challenge in this area [62]. Therefore, we can expect that this is challenging for audio based technologies as well. There is also an increasing interest for multisensory technologies relying on olfaction and taste, especially for museum experiences [38, 50, 13]. For instance, Hollinworth *et al.*, invited children with disabilities to create sensory boxes to accompany and share their museum experiences [38]. However, this project does not address the challenges arising when it comes to communicate non-verbal sensory experiences from one person to the other to convey a specific meaning.

In conclusion, this related work highlights the enduring predominance of the visual paradigm in most technologies that may be useful in our context. We pointed out how it reinforces the legitimacy of certain forms of knowledge, and how technologies based on another approach of the sensory may be used to challenge them [81, 34]. We also outlined challenges to consider: scaffolding the experience (e.g., by directing attention through specific questions), and providing tools to enable a shared understanding of non-visual, non-verbal, experiences.

CONTEXT AND METHODOLOGY

The research presented here is one aspect of a larger interdisciplinary research project in HCI, social sciences and design, investigating children's experiences of school and what could eventually improve them. It was conducted in a French non-profit organization providing various services to children with visual impairments[2]. The organization also organizes community events, such as parties for children, trips to amusement parks, afternoons to discover adapted sports etc. We use *care-givers* as a generic term to designate all adults engaging with children on a regular basis and for several years (e.g., teachers specialized or not, educators, parents, etc.).

[2] Services include assistance in acquiring independent living skills (e.g., educational intervention in the family, orientation and mobility); Rehabilitation and therapy (e.g., speech and low vision therapy); Adapted documents and human or technological aids to children attending mainstream schools exclusively; Classes to acquire specific skills (e.g., reading braille, reading tactile documents) to children attending a mainstream school the rest of the time; And finally, segregated classrooms for children with multiple and profound impairments.

Methodology

We took an inductive participatory approach to the research [18]. We favored qualitative methods because we were interested in subjective experiences of school at the individual level (how people think and feel) [46]. We conducted observations in the aforementioned organization for one week every month over the course of 18 months (November 2014 to June 2016). These observations involved about 50 youngsters from 2 to 19 years-old and 30 caregivers. For the needs of our investigation, we completed observations with interviews, and the co-design of a technology probe [39]. We expand on the rational behind the choice of methods at the beginning of each following sections.

Inductive thematic analysis

Thematic analysis [16] consists in describing the research material by associating codes with chunks of data. Themes are derived from these codes through the identification of categories and patterns, rather than by predefined research questions. For instance, the inquiry presented in this paper was prompted by the regular expressions by teachers and therapists of their difficulties to understand how children make sense of sounds for learning; and by children's eagerness to make audio recordings in contexts other than field-trips (where it was not allowed initially).

We developed two codesheets. One to describe activities and hearing techniques during field-trips, such as the types of cues recorded, and how they were used. The second identifies expressions of values, understood as judgments guiding human conduct [21], and codify statements by the different participants about what the goals of education, what children should learn, and what factors affect success at school. They are often marked by the differences highlighted between different situations and children. During analysis we examined the gradations and contradictions in values and how they were explained to understand the initial and evolving opinions of the research participants. These codesheets can be found in the auxiliary material.

Ethics

The project aims and methods were devised with the organization's employees, and presented to parents, who agreed with their children participating in the overall study. The probes we deployed were designed with teachers and children, so it would fit in their usual activities. The field researcher was careful to explain to each children, in a way they can comprehend, the goals of her visits. Ethical issues were carefully considered as they arose, following the UNICEF's guidelines on research with children [32]. One of these guideline is the importance of supporting marginalized children and their communities in expressing their views and attaining desirable changes. Re-examining learning activities in light of the sensory turn, and its opposition to the dominant visual paradigm, is thus well in line with these guidelines.

Process

This investigation was three folds: the first consists in describing the use of field trips in geography, from our observations and interviews. We argue that there is a paradox: though necessary, the hearing knowledge developed during field-trips is often under-valued by both children and teachers. The second consists in defining a design intervention, through interviews with carers and the co-design of a probe with children. The third is the deployment of the probe, which we observed and discussed with all participants, to understand if and how using the probe changed their perspectives on auditory knowledge. We now detail these three steps.

STEP 1: ANALYSIS OF FIELD TRIPS PRACTICES

We first set out to understand pedagogical practices aiming to teach geographical knowledge. In many aspects, they do not differ from the recommendation to teach geography to all primary school children [25]. Teachers often adopt an inductive approach, where learning starts with a given place and a given number of traits, towards more general concepts. One way to do so is to compare two places, their similarities and differences. Another is to "zoom out": showing how a neighborhood fits into a city, county, etc [30].

However, one aspect of this teaching in the organization studied stood out: the importance given to geography field-trips, specifically to sensory experiences during them. Yet, as pointed out in our review of geography scholarship there are no clear guidelines on how to use non-visual cues to support meaning construction in this discipline. Thus, we observed and conducted interviews about 5 field-trips, during between 3h and a day. The student-teacher ratio was 5 to 1 on average.

Why Organizing Field-Trips.

According to teachers, the primary goal of geography field-trips is to reduce *misconceptions* in mental representations of space and environmental features, in order to exemplify and explain curriculum concepts (e.g., discovering different types of roads to explain networks and land use and transport planning). In their words: "*Field-trips [are] about describing things precisely, specifically, with the visual impairment in mind. Especially abstract concepts. Otherwise they can't think about the world [...] they may use the right words, but not know what it means. We need to give them adequate mental representations.*"

Teachers also reported that supporting children in constructing adequate mental representations is a complex art. The difficulty is that children lack means to express what they understood, and teachers lack means to capture what children understood: misconceptions are revealed incidentally (e.g., when a child is asked to describe a plane and mentions it rolls in the air like the aerial transit system). Developing adequate pedagogical practices without this mutual information is thus challenging, especially when considering that "*[the representations useful] for one child might not work for another one*". A secondary goal is to provide an enjoyable experience (which should increase motivation [22]).

Observation 1 (O1): Field trips are used to reduce misconceptions that would lead to a misunderstanding of curriculum concepts. However, understanding children's mental representations (teachers) or expressing them (children) remains challenging.

How teachers point out and describe sensory cues

The previous example points out two essential phases for using non-visual cues from the environment to construct meaning. They need to be localized and discriminated from others as meaningful, and thus pointed out; and they need to be described in terms of causes (e.g., the noise of the plane is due to its motors, the one of the aerial transit systems to the friction between the wheels and the rails). Indeed field-trips provide many sensory experiences that teachers can exploit. They may refer to all the senses: hearing, such the echo inside a church; kinesthetic and tactile, like a walk along its walls and the texture of its stones, etc (see Auxiliary material).

However, the sense of hearing was the most used (which is consistent with [82]). These sounds come from the built infrastructure (e.g., outside: roads, public transportations; inside: echo, automatic doors), human activity (e.g., discussions, walkers, firemen sirens); and the natural environment (e.g., wind in the leaves). Teachers point out and use sensory cues in a variety of ways. For instance, teachers may point out useful cues and associate them with a description useful to introduce the concept they wish to convey. As an example during a lesson on human habitats (urban, suburban, rural) and their economic features: "*[with echolocation] you can feel it's a large open space [...] you can hear the cars and lots of people because they are talking [...] yes it sounds kinda like a shop but not exactly that [...] It's a restaurant, and a restaurant in a large open space probably means a public square. What do we find on the town square? This is a town square. We find [...]*" (see Auxiliary material for more examples). **O2:** Teachers make use of all types of sensory cues to construct meaning, with a clear preference for using audio cues.

How teachers scaffold field-trips.

Prior to the trip, the teacher visits the site(s) to devise a list of stops that can serve as example of the curriculum concepts to introduce. At each of these stops (e.g. during an outdoor field-trips the war memorial; during a museum field-trip, a statue), the teacher provides a short lecture. This is followed by a few questions to assess children's understanding. In a few occasions, she rather provides a problem statement and asks children to make hypothesis. The codesheet provided as auxiliary material provides examples for these techniques.

Before the field-trip, teachers may introduce necessary concepts, or a map of the general spatial organization, to which they can refer later. After the field-trip, activities are organized to reinforce children's learning by asking them to reflect on what they experienced. It may consist in working on the same or different map to further generate hypotheses on the phenomena explored (e.g. the differences between cities and villages). It can also consist in reporting the trip in a multimodal fashion, such as texts in black and braille with images. In the teachers' words: "*The field-trips and the artifacts I bring to the classroom are to provide as many information as possible, and many different and complementary representations of a concept [...] You have to vary the approaches, and accompany them in bridging the gap between the experience and the mental representation*."

Our observations also suggest that teachers sometimes struggle to establish ties between the lectures given during the field-trip and follow-up activities. Sometimes, too much time passed during the field-trip and the next class (e.g., because of holidays). The best way to do so is to get to learn children's interests and preferences to select the memory that helps developing an explanation. For instance: "*[With this pupil,] you can be sure he's going to remember everything related to food. But [this other pupil] is rather going to remember everything that made him laugh, or that have emotional significance*". However, getting to know children's preferences takes time, and according to the teachers' interviewed, such knowledge is difficult to transmit to future teachers, as it is never really formalized.

O3: Teachers attempt to link field-trip sensory experiences with representations such as map before and after the field trips to provide multiple and complementary perspectives on the same curriculum concept.

Use of technologies

We observed a limited use of technologies during the field-trips: Teachers use cameras to take photos. Sometimes these photos are reused later on in the classroom, or they may be sent to parents. Teachers did not initially identify the absence of technologies as an issue. Indeed, they were not convinced that children could meaningfully use technologies in this context by themselves. Reasons include concerns over safety, and children's perceived lack of reflexivity: "*If I give them a camera, they're just going to record anything and everything, and it'll be impossible to get them to focus*." However, children sometimes worked with a geo-technology, an interactive map (similar to [9]), once back in the classroom. While, not directly related to the field trip itself, this system uses audio recordings found online, mostly to reinforce engagement through playfulness.

O4: Teachers usually do not use technologies except for cameras during field trips.

Children's perspectives

Children mostly describe field-trips as an enjoyable experience, the secondary goal of field-trip ("*I like field-trips because I don't have to go to school!*"; "*Field-trips are a reward for the children who obey well*"), but also that they appreciate to be more physically active ("*It's better than being seated*"). One indicated being more autonomous in field-trips to the museum, because, as each tactile object could only be held by one child at a time, and there was not enough time to manipulate each artifact, there is a choice to be made ("*you can decide a bit more what you want to look at, that's cool*"). When asked what they learned during field-trips, the experience was either labeled as similar to classroom activities, or as non-relevant to learning ("*we learn, you know, the usual stuff*;" "*it's not really learning, it's more like stories*"). Finally, we note that their agency remains quite constrained: they do not often initiate activities (e.g., by asking questions), they can not explore freely outside sites and are often limited to small areas in museums (for safety or accessibility reasons).

O5: Children value field-trips as an enjoyable experience, but either do not consider them to be a learning activity, or consider it is not different from the classroom.

Synthesis and issues

Organizing geography field-trips is a rich and complex practice which appears useful to reduce misconceptions about objects and environmental features (**O1**): Teachers make use of different sensory cues to help children make sense of their environment (**O2**). The sense of hearing is usually the most used (**O2**), which is not surprising as our review of literature [82, 3] suggests it complements vision well to develop geographic knowledge. Moreover, teachers attempt to link field trips experience with a variety of other representations (e.g., maps, small scale models) before and after the field trips to provide complementary representations of the same concept (**O3**). But capturing children's mental representations (teachers) or expressing them (children) remains challenging (**O1**). From this perspective, teachers value field-trips and non-visual knowledge.

However, further analysis reveals a tension in the way children and teachers describe field-trips and the way they perceive the knowledge thus acquired. For instance, children qualify field trips as an "enjoyable experience" but not as a learning activity (**O5**). This may impair children's ability to reflect on how they learn [26]. Furthermore, teachers also described field-trips as simply a playful *introduction to a curriculum topic*. In their words: "*It obviously helps, but it's the foundation on which they learn, not what they need to learn. What's important is the concept, the abstract*". More surprisingly, they suggested that not all children benefit from field trips: Field trips are for children lacking cultural [52] and familial resources. In contrast with a child needing these field-trips, a teacher stated: "*Him, his parents describe everything, all the time. [...] When the parents don't do that, or don't know how to do that, it gives a lot more work to get to the actual learning*."

As a result, field-trips are a lot less used with children performing well academically, not necessarily because they know how to interpret new sensory experiences well, as it remains implicit for them, but rather because they are able to use graphic representations to answer tests correctly. Hence field-trips and sensory knowledge remain confined to visually impaired children with learning difficulties, rather than being used as an inclusive learning experience for all, as advocated in Geography scholarship [45]. We call this tension the paradox of *using non-visual knowledge in the classroom.*

Finally, we learned that children do not use technologies during field trips, and that teachers only use cameras (**O4**). Existing technologies are designed to be used in the classroom and mainly aim at substituting vision with another modality (e.g., [7, 92]). Furthermore, teachers did not use the interactive map in their possession to articulate children' sensory experiences with the map representation. This observation is in line with our initial argument, which is that visual-based representations are perceived as more important in learning, hence explaining the choice of designers to target this type of knowledge.

ID	Age	Gender	Grade level	Type of impairment
C1	11	Male	5th grade	Blind
C2	11	Male	5th grade	Severe visual impairment
C3	10	Male	4th grade	Severe visual & hearing impairment
C4	10	Male	3rd grade	Blind, motor impairment
C5	11	Male	4th grade	Blind, learning disabilities

Table 1. Demographic information and grade level of children participating to the design and deployment of the probe.

ID	Age	Gender	Occupation
CA1	46	Female	Specialized teacher
CA2	38	Female	Librarian

Table 2. Demographic information of the teachers cited in this study.

STEP 2: DESIGN OF A PROBE

We decided to investigate how we could support the use of hearing techniques in this context. The initial idea consisted of allowing children to record audio cues of their choice during field-trips and to use them in later learning activities. We now detail the design process.

Defining the design intervention with caregivers

To define the design intervention, we used semi-structured interviews to better understand constraints to take into account in the design of such technology. We also conducted eight interviews with caregivers (including four therapists) to understand practical and ergonomic constraints.

From these interviews, several requirements emerged. When asked about whether they would let children use such a device, carers were initially quite reluctant. They fear that it would be distracting, and therefore unsafe in an outdoor environment. Some caregivers was however eager to give it a try, in order to better understand what children learned. They wanted the probes to be task focused, robust (both in terms of supporting a potential fall and in being re-usable even after the departure of the researcher) and inexpensive. These requirements led us to *not* give children smartphones and smartwatches. Furthermore, carers forbid us to place a device on the cane or to be hand-held, based on concerns for children's safety during navigation, as they would not receive the training usually required to use a new device in mobility[3].

Co-designing probes with children

To engage children in the process, we proposed them to co-design a technology probe following these requirements. Probes are devices or tools used to provide design inspiration, better understand people and their uses of technologies, field-test technologies [39], used as means of engaging users [6]. They are technically simple and flexible: participants are encouraged to invent new ways of using them. In this case, they were also a way for us to embody values, and investigate how participants would adopt, negotiate or challenge them by judging this probe and its uses.

We involved five children, who had earlier been involved in the field-study. Their demographic and other information

[3]This was confirmed by children during a design session. They insisted it should not be hand-held nor placed on a cane, as it adds complexity.

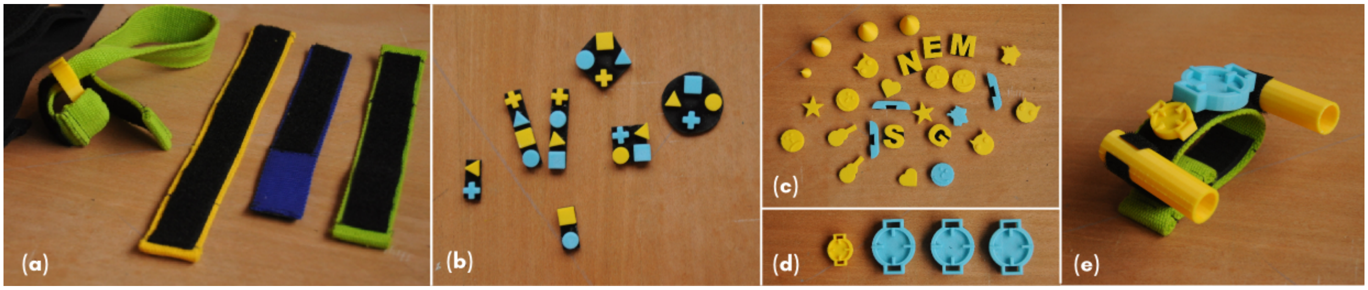

Figure 1. The first version of the probe is a Wizard-of-Oz prototype. It consists of (a) straps of various lengths that can be customized by: (b) small 3D printed shapes that can be easily discriminated tactily and used as buttons; (c) various 3D printed modules and geometrical volumes; (d) watch faces. (e) This probe was designed to enable children to build bracelets like those of superheroes / spies, watches or friendship bracelets. This is an example of a "spy bracelet" made by C3.

are reported in Table 1. They attend different mainstream schools part-time (i.e., 3-4/5 days of the week) and the same segregated classroom the rest of the week. Their time in segregated classroom is dedicated to develop specific skills (e.g. reading braille) and attend rehabilitation sessions (e.g. mobility and orientation).

We conducted a brainstorming with the children participants for the first version of the probe. Once the probe deployed, we collectively decided to take another approach, and devised a second version driven by practical concerns.

Version 1. For the first version, we conducted a brainstorming to emphasize the playfulness of the probe. In doing so, we hoped children would see the device as something valuable and fun rather than something made to compensate disability. We focused on the form that children would like, building upon the results of a brainstorming on "*a device to make audio souvenirs when going on a school trip*". We relied on examples from pop-culture to discuss its appearance: we asked them what kind of characters they like would have such a device. The characters proposed by children were either super-heroes (e.g. Batman) or spies and detectives (e.g. Spy kids). When describing devices, they proposed that it could look like common watches (C1: "*So no one notices but it's cool*"), that it could look dangerous and impressive (like Batman utility belt), or that it could be playful and distinctive (C2 proposed it could be friendship bracelets for people who like the same football team for instance). C4 also asked for tangible buttons, and the others agreed. In order not to limit design possibilities or have too bulky or unreliable prototypes, functions would be simulated by the field researcher (i.e., Wizard-of-Oz prototype [20]).

Given the variety of ideas proposed by children, we designed a kit (Figure 1) to make one's personalized wearable device. It consists of a series of straps, which can be worn anywhere on the body, and of a set of 3D printed modules. Both are covered with velcro to be assembled easily (Figure 1). The modules were 3D printed and can be discriminated tactily. They consist of small buttons (e.g., a cross, square, circle and triangle–Figure 1-b), decorative elements (e.g. guitars, tubes or cones–Figure 1-c), and watch faces (Figure 1-d).

Version 2. However, it was quite difficult to follow each child, which frustrated them–and this approach was unsustainable for

Figure 2. The second version of the probe is worn on the wrist. It consists of a strap covered with velcro on which an audio recorder/player.

the teachers. We therefore consulted the children and carers regarding a variety of commercially available recorder options that we could use for a second version of the probe. This was a collective discussion. Children found that "professional looking" audio recorders were acceptable, and carers agreed to an audio recorder using three simple tangible buttons. We thus bought five Nestling Audio recorder of 83x35x12mm, with velcro sticked in its back to attach it on the wrist. They are pictured in Figure 2. The three main functions—Play/Pause, Stop, Record—are accessed by three physical buttons that can easily be discriminated tactily. They are cheap (12$) and resistant to falls as required by teachers. Five of these devices were made available to the teachers. Note that we chose to use a commercial device rather than assembling them ourselves in order to guarantee that they could be used after we left the field (as required). But this poses usability issues, as there is no audio or tactile confirmation of the device status.

STEP 3: PROBE DEPLOYMENT AND ANALYSIS

To understand how the use of the probe affected practices, and whether it changed children's and teachers' points of view on sensory knowledge, we used two methods: observations, and follow-up interviews with each of them. The first version of the probe was used by the five involved children in a class trip of 2 hours led by CA2 to a history and geography museum, to learn about the roman empire and its myths. The second version was deployed three months later during a class trip of 2 hours to an outside site to study the differences between rural and urban environments. It was led by CA1 for a geography course (with C2, C3, C4 and C5, i.e. four of the five children who used the first version. C1 was absent that day). Children were invited to *create memories* and *record sounds*. For each audio recording, she asked the children why it attracted their attention. Children could also ask the field research to take photos or videos: by doing this, we hoped that if necessary children could contradict us on the importance of sounds, and would use something more appropriate to them if needed.

Recordings made by children

There were only a few recordings made with the first probe. This is probably because there was only one researcher/Wizard-of-Oz to make them, and because children were not yet used to such device. During the two-hours trip with the second version of the probe, many more recordings were made: between 10 (C5) and 28 (C3) minutes of material. Some recordings were initiated by the teacher (3 recordings of about 10 seconds), but the rest of the recordings were made by children. These recordings were of various types (e.g., messages, stories, sound effects) and are documented in Auxiliary material. Finally, they asked for 18 photos in total, and no videos. Photos were taken of elements they were interested in, because of their other sensory aspects (e.g., wind in the leaves, sensation to pass from one space to another–which is consistent with Herssens' *et al.*, investigation of children's sensible experiences of architecture [37]).

How lectures were redesigned

We observed a number of changes in how the teacher handled the lectures, which became more interactive. For instance, in the example about public squares page 5: a cue is given, and a lecture follows. Compare with the following: "*How can we learn about what is around this village square? [...] Yes we could walk around [...] We can ask people [...] And we know things about village squares. What do we find there usually? [...] Indeed, a church, and sometimes the town hall. How does the Church sound? [...] Very well, indeed it has bells! Let's record them. And why is there a church in the center of villages?"*

The presence of the recorder seemed to play as an incentive to develop active lectures, tying in more complex ways curriculum concepts with surrounding sensory cues. Children were also more invited to elaborate on the kind of cues they could rely on, instead of having these cues pointed out. It also introduced the idea that children could take note by recording either sounds or lectures–written notes would in this case be difficult to take.

Another impact is that children shaped the lectures: They took the initiative of asking the meaning of sounds they were noticing, which we had not observed before. It also opened new opportunities to cooperate with their classmates. They would record messages to "send" to one another, or cooperate to not record the same thing. This was quickly identified by the teacher as an opportunity to develop their learning techniques, but also as a potential nuisance enabling them to play instead of focusing on the activity.

How recordings were used

Children devised unexpected ways to use sounds: for instance, they used non verbal content to answer a teacher's question or added playful sounds to museum exhibits (see other examples in auxiliary material). It also revealed something that we did not understand through observations only: children *produce* the sensory cues they need to construct meaning. For instance a child recording the noise made by his cane on the ground (pavement often indicates older streets, or streets preserved for their historic significance, than concrete).

Scaffolding

These audio recordings were used after the field-trips: Those from the first field-trips were used for multimodal storytelling. Those from the second field-trip were used to customize an interactive map, similar to [7]. The teachers involved also suggested improvement to the device, and ways to integrate it further in their activities. We will not expand on impacts on learning during these activities. As the focus of this paper is whether or not the probe enabled participants to change their perspectives on the sensory knowledge acquired during field-trips, if it made it more legitimate to use. The fact that these recordings were used in the classroom suggests so. But participants' perspectives are more interesting to us.

Teachers' perspectives

CA1 pointed out that the probe made her rethink what would be pertinent audio material for representing curriculum concepts: "*I wouldn't have thought about recording or recording some stuff they recorded, but if I know how it makes sense for them [...] I can use it*." CA1 observed an impact on memorization as well, whereas remembering the details of the field-trip was initially framed as a problem. Meanwhile CA2 underlined: "*I wasn't convinced, as it seemed to be just fun, but I really was able to use [these recordings] afterwards, to help them engage*." We find here the two stated primary purposes of field-trips: reducing misconceptions in relation to the curriculum, and engaging children. Yet auditory material was not confined to the field-trip anymore: it was fully recognized as a material to be used in formal learning activities, including those conducted in a mainstream classroom with their sighted peers: "*I think the most important isn't even cognitive, it's the fact that it changes how their classmates see them*". However, she also pointed out that field-trips are difficult to organize for larger groups which limits their use in a mainstream context. Finally, the first version of the probe inspired other teachers, not involved in the design process, to develop interactive bracelets to support embodied learning in a totally different discipline (i.e., maths).

Children's perspectives

As for children, several elements contrast with their initial perception of field-trips as a fun activity not related to learning. Two of them (C3 and C5) asked if their recordings would be evaluated, suggesting they did consider it as schoolwork. Related to that finding is C2's expressing that using these recordings afterwards indeed made them legitimate–"*when you record it and you use it in class, it's not silly*." On the other hand, children wanted to *share* these recordings, among themselves and with others. Although after earlier field-trips, we did not see them talking about what they had heard, after using the second version of the probe, C4 came up to ask us

Figure 3. (a) The first version of the probe is non interactive. Children used it to built tactile bracelets and generate novel scenarios for documenting and reflecting on field-trips (here, in a museum). (b) The second version is a functional bracelet recording and playing sound.

for the recordings to "show" it to one of his friend. Which confirms teachers' perceptions that an approach including non-visual material indeed enables these children to share with their sighted peers.

Of interest to us are the particularities in children's responses, which can nuance our findings: C3, who has a hearing impairment, still greatly used the probes. From our discussions, it seems that it was easier for him to record on the moment and review it later, that it helped them discriminating between different audio sources (e.g., the lecture and the environment). As a result, he reported feeling better understood. But children had very different levels of involvement, as exemplified by the length of the recordings made, and by their feedback. C1 and C2, who do not have additional impairments and are in a more advanced grade, were more critical others. In C2's words: "*it's more about fun, and helping the others, ain't it? It's good it helps them*." Further in the interview, both of them pointed out that it was different from what sighted children do. If C3 outlines this difference as positive, C1 and C2 see it as negative. Which begs the question: Should we, and how do we, extend the invitation to consider non-visual sensory knowledge to the sighted?

DISCUSSION

Changes in Perspectives

Building upon a review of the literature we argue it is crucial to support the development of non-visual knowledge of geography. Not only this enables to support geographic learning from children's embodied experiences, but it is also a matter of questioning (1) the implicit dominance of visual material in learning, (2) who have access to this knowledge, and (3) how it is supported materially. Our work exemplifies how (geo-)technologies or their lack contribute to the legitimacy of a given knowledge. Indeed, the introduction of the probe, centering on the sense of hearing, impacted children's and teachers' practices and narratives. It changed their interactions during field-trips, and the type of material used in the classroom. It also altered how and to whom children talk about field-trips, and ultimately of the value of hearing knowledge. The flexibility of the probe was probably a key factor in doing so. Rather than presuming what type of recordings would be useful, or proposing structured activities, our intervention was light, and focused on enabling children to manipulate audio material in geography.

Transferring findings: The importance of mediation

Though an increased use of hearing techniques and auditory material in learning activities was well received by this group of children, it does not guarantee the same effect in a different setting. For instance, in a mainstream classroom, the difference with sighted peers can be perceived positively or negatively, in our case depending of academic advancement. Therefore, we can speculate that the changes discussed in the previous paragraph would occur differently in other contexts. Hence, rather than *generalizing* our findings, which would imply reproducibility, we argue we should focus on how to *transfer* our findings.

Adopting our approach successfully requires to consider the mediation made by researchers. In our case, we used our theoretical lens to understand, support and extend local practices that pre-existed our intervention. But if we had a different lens, results would be different. A risk we identified, for instance, is to present this kind of artifact as a way to make sighted children empathize with their visually impaired peers (e.g., by blindfolding them). First, many people with disabilities find this offensive [4]. But mimicking disability also misses the point: blindfolding can only be restricted to one moment in time, providing a superficial experience. By reducing auditory knowledge to a way of developing empathy, we obscure the real issue: The need to question which and who's knowledge is considered suitable at school, and to support a diversity of ways of knowing. This implies that instead of presenting to children visual impairments as a lack, we should fully take them into account in the design of courses, or present it as enriching school activities. To teachers, it can be presented as beneficial for out-of-school learning. Indeed, learning to be attuned to environmental audio cues in Geography classes afford new occasions for geographic concepts to be used in children's everyday lives. We would argue that this could be done by designing the pupil with visual impairments as the *expert* in hearing techniques, within a larger classroom dynamic encouraging the shared expertise of teachers and children [8].

The roles of probes

We used a probe to engage participants, inspire new designs, further understand uses of field-trips and support the use of auditory knowledge in Geography. Although we envisioned it a technology probe [39], it fostered the empathy central to the use of design probes [85]. Indeed, it required the field

[4]See for instance: http://bit.ly/1d8049z;
and disability.illinois.edu/empathic-modelingdisability-simulation

researcher and teachers to take more seriously their auditory environment as well as to children's sensory experiences **by design**. In the first version, the researcher acted as a proxy for children. And with both versions, it required constant reflexivity to understand what children found meaningful and why. We would suggest that children were grateful to this effort: their narratives focus on being **recognized** and taken seriously, by their peers and their teachers. However, the probe also created tensions between teachers and children regarding acceptable and unacceptable uses (they value differently seriousness and fun). As such, probes seem a useful tool to investigate values in design (see also [53, 84]).

Considering the Senses as a Culture

More generally, this paper is an invitation to consider the senses as a culture when designing novel technologies. Theoreticians of the sensory turn remind us that our ability of using our senses for learning is culturally shaped [64, 14, 58]. It is an invitation to design for supporting marginalized knowledge [70], in interaction with formal knowledge. Or as expressed by McBride [68], to "*design from the margins*." Matos' work on a rare whistled language [66] is a good example of this. It also is an invitation to consider how the senses and sensory knowledge are currently, and could be in the future, mediated: Are all sensory knowledges acquired through similar practices (e.g., pointing out and describing)? Are the scaffolding techniques we outlined the same in other contexts?

Our findings provide a number of insights on how a non-visual knowledge of geography. Some of our findings echo those made in other domains or with other senses. For instance, the use of metaphors we observed can also be found in [64]. Or in the case of smell, [68] advocates to devise ways of producing scents. It could be paralleled with how children learn to produce a number of different sounds to acquire information or express what they mean. And as metaphors are culturally specific (think about how difficult it can be to translate an idiom from one language to the other), how can we support cross-cultural approaches?

Pragmatic implications for design

Finally, we outline a few opportunities for design, particularly for accessible geo-technologies. We argue our findings on the types of cues that can be used opens new perspectives for auditory representations of space (e.g., maps [72]). Instead of using symbolic cues to represent city areas, it could rather use more complex and realistic sounds, representative of their differences. For instance, touristic areas have a very different sonic ambiance than industrial areas. Furthermore, whereas research on full-body interactions have focused on visual attention to foster learning in a variety of disciplines (including natural sciences–see [61, 62]), the field-trips practices we observed (and the later uses of audio material in the classroom) suggest that auditory attention may be used as well. Because children are not as used to identifying audio stimuli as to identify visual stimuli, they may have to be more attentive to them.

CONCLUSION

In this paper, we argue for using the sensory turn as a lens to examine the learning experiences of children with visual impairments. We described the rich practices of teachers to teach children how to use their senses to understand their surroundings and construct geographic knowledge. However, teachers and children were conflicted about the value of this sensory knowledge, which we call the paradox of using non-visual knowledge in the classroom.

We designed a probe enabling children to make and play audio recordings during these field-trips, recordings that could then be displayed on an interactive map or other supports. Through observations, we show changes in practices, and particularly increased agency for children. Through follow-up interviews, we demonstrate a change in discourses, hinting at a re-evaluation of the auditory sensory knowledge of space. Which confirms our initial stance: designing for a diversity of ways of learning and knowing contributes to enable the expression of marginalized views.

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